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Technical Memorandum **80308**

# **A Catalog of Jovian Decameter Radio Observations from 1957 - 1978**

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A CATALOG OF JOVIAN DECAMETER-WAVE RADIO  
OBSERVATIONS FROM 1957-1978

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## Abstract

A catalog of over 200,000 hours of observation of Jupiter radio emission in the decameter-wavelength band has been created on magnetic tape and is available upon request. The data have been collected from 13 observing sites which are part of synoptic monitoring programs started by the Universities of Florida and Texas and the Goddard Space Flight Center. Observations were made at 14 fixed frequencies from 5 to 30 MHz. The characteristics of the tape recording technique and the data format are described. The combination of overlapping data from observing sites scattered world-wide lessens the effect of the earth's daily interruption of the ground-received signal. A power spectral analysis of the data shows no evidence of periodicities within the data other than the well-known influences of Jupiter, Io, and the earth. The dependence of the occurrence probability of emission on System III longitude and the phase of Io varies smoothly with frequency down to 15 MHz and then appears quite different at 10 MHz. The morphology of the radio sources is both complex and stable for periods of at least months and probably much longer.

## Introduction

Ever since the discovery by Burke and Franklin in 1955 (reference 1) of decameter-wavelength Jovian radio emissions regular observations of Jupiter have been conducted in the 5-30 MHz radio band. This publication describes a data catalog, available on magnetic tape, merging three large sets of fixed-frequency observations from the Universities of Florida and Texas and the Goddard Space Flight Center. The Texas and Goddard data have been published previously (references 2 through 7), but the present catalog represents the first convenient access to the Florida data as well as a valuable combination of over 200,000 hours of observation at 14 frequencies in a common format.

A large data base is important since Jupiter emission occurs only sporadically. Despite over two decades of effort the many facets of the Jovian decameter emission (often called DAM) defy a comprehensive explanation. DAM, however, exhibits periodicities on time scales from milliseconds to years and a complete picture of the phenomena has been difficult to obtain even in the 24 years since discovery. Not only is the emission itself intermittent, but the ground-based observations are usually limited to the nighttime hours when the ionosphere becomes quiescent, decreasing terrestrial interference with the planetary signal. Similarly, solar interference prevents data acquisition near the time of Jovian conjunction with the sun.

To combat these problems several groups established synoptic

monitoring programs involving widely-scattered observing sites, thus increasing the chances of favorable observing conditions. As we shall see, even these groups miss a large portion of the emission. For a clearer understanding of the emission process a combination of the results of these various groups is valuable. This publication describes such a merged data base and some of the basic uses of it. It is hoped that others will find this catalog useful in the intensified research on DAM which has been stimulated by the Voyager mission (references 8 and 9). The data are available on magnetic tape and can be provided on request.

The next section presents a brief overview of the three synoptic monitoring programs which have provided the data for this catalog. This is followed by a listing of the particulars of the tape containing the combined data. The final section reports the results of some of the fundamental analyses which can be performed with the data.

### Synoptic Monitoring Programs

As mentioned above, the Universities of Florida and Texas, and Goddard Space Flight Center have served as collection points for the majority of fixed-frequency data taken during the past twenty years. Figure 1 displays the locations of the observing sites participating in these programs, identified by a code letter which is interpreted in Table I. The University of Colorado is absent from the list although it is noted for extensive observations of Jupiter at decameter wavelengths using

a swept-frequency spectrograph. These records are important for overall studies of Jovian dynamic spectra, but a determination of Jovian emission behavior at individual frequencies is difficult to extract from their catalog. A summary of these data are to be found in Warwick et al. (reference 10).

The University of Florida began its regular observation program in 1957 at a frequency of 18 MHz. Since that time other data have been acquired at a number of frequencies (see Table II). The Maipu Radioastronomical Observatory in Chile was established in cooperation with Florida in 1960 and this added to the observations at 10, 15, 18, 20, 22, and 27 MHz while also inaugurating the frequencies of 5, 13, and 16 MHz. For a short period from 1964-66 a second observing site at Huanta, Chile contributed to the 10 and 18 MHz data. A description of the equipment and the method of data reduction can be found in H. I. Register's Ph.D. dissertation (reference 11).

A synoptic monitoring program was begun by Yale University in 1957 and in subsequent years observations were carried out at 10, 16, 20, 22, and 23 MHz. A site established at Kodaikanal, India contributed data from 1962-67 at 22 MHz. In 1967 the Yale program was moved to the University of Texas, and the frequencies of 19 and 23 MHz were discontinued, but valuable observations at 30 MHz, nearer the upper cutoff of Jupiter's DAM emission, began. The results as incorporated in the present data base are tabulated and described in greater detail in the catalog published by the University of Texas (reference 7).

A group at Goddard Space Flight Center, with the help of the

University of Texas, began the GSFC Jupiter Monitor Network in 1965. The only frequencies studied were 16.7 and 22 MHz, but the equipment was located at NASA Spacecraft Tracking and Data Network (STDN) stations scattered throughout the world with the intention of continuing observations around the clock. The difficulty of maintaining the equipment and the shutdown and relocation of many of the sites allowed this goal to be realized only for short periods. Nevertheless, the network has provided extensive records of Jupiter activity.

It should be noted that the Texas and GSFC/JMN data were obtained by interferometer pairs or arrays of antennas and consequently the occurrence probabilities are usually higher than data from Florida at comparable frequencies (see Table II) where individual Yagi antennas are the usual equipment. It is difficult to compare the sensitivities of the many observing sites since the values change with time, equipment, maintenance of equipment, ionospheric conditions, etc. All estimates of threshold flux densities for detection of Jovian activity, however, fall in the range from  $10^4$ - $5 \times 10^5$  Jy.

#### Description of Data Tape

All of the previously-described observations have been reduced to a common format and merged on a single magnetic tape. Each record on the tape represents a continuous period of either listening time or Jovian decametric activity in accordance with the form outlined in Table III. The records are sorted by the



following keys in descending order of importance:

1. frequency
2. year, month, and day
3. station code letter
4. beginning time of listening or activity
5. listening or activity code

Since there are presently almost 100,000 records in the catalog, a listing of all of the data is too bulky for publication. Detailed information is easier to obtain directly from the tape. The tape currently in use is unformatted and has been generated with the following data definition parameters using an IBM 360 computer:

1. 9 track tape
2. 1600 bits per inch
3. standard label
4. logical record length = 48 bytes
5. variable blocksize
6. maximum blocksize = 32644 bytes
7. volume = serial = JPCAT1
8. data set name = JUPCAT

The last 44 bytes of each record contain the eleven four-byte words described in Table III. Note that Table III also lists the FORTRAN variable type of each of these words. The tape characteristics and the formatting of the data can be readily changed for compatibility with another machine.

#### Initial Data Analysis

The major purpose of this publication is to document the existence and availability of the decametric observations catalog. Detailed analysis would unduly lengthen this work, so the present section will be limited to analyzing and displaying the major characteristics indicative of the quality of the data, such as the purity of the basic periodicities in the data and the extent of filtering of earth environment influences from the Jovian emission. The temporal and spectral behavior of earlier subsets of the catalog was studied in greater detail in two previous publications (references 12 and 13).

The importance of combining data from different stations is indicated by Table V. Listed are occurrence probability statistics for simultaneous observations at 22 MHz by various pairs of stations. Though these stations are all in the western hemisphere and some of them are separated by less than a thousand miles, the total activity seen by both stations during the same observing times is usually much less than the activity time identified by either station individually. Variation in equipment and sensitivities, changing ionospheric conditions, misidentification of storm times, etc. can explain these differences, but the important point is the improvement of data quantity and quality obtained by combining overlapping observations.

The periodicities in the data are apparent in Figure 2, which compares plots of spectral power versus period for 20 years of Florida 22-MHz data versus all cataloged 22-MHz data for the same period. Relative spectral power has been computed using the

method of Kaiser and Alexander (reference 14). The major peaks are labeled according to the harmonics of the principle periods which combine to form them. The four major periods are: the earth (E) and Jupiter's (J) rotational periods (24 hr. and 10 hr.), the Jovian synodic period ( $J_s$ ) relative to the earth (399 days), and Io's synodic period (Io) as viewed from Jupiter (13 hr). The prominent peaks are labeled in the lower plot by the low-order harmonics of these major periods which combine to form them. A fifth periodicity caused by the 12 year variation of the Jovicentric declination of the earth is too long a time interval to be included in the graph, but the perturbations apparent from this cycle are nevertheless quite important to DAM theory. For further discussion of this effect see the summary by Carr and Desch (reference 15).

The overpoweringly dominant 24-hour peak in the Florida data in Figure 2 is an artifact introduced by earth-based observations which, as explained earlier, are usually confined to nighttime hours. Because of this nocturnal cycle the morphology of Jupiter's emission must be pieced together from a multitude of data widely scattered in time, or, from consecutive records of observatories scattered around the world. In the lower part of Figure 2, the influence of the earth's rotation has obviously been diminished by combining all 22 MHz data within the catalog. This increases the relative size of the smaller maxima and simplifies the search for minor peaks indicative of periodicities dependent on some source other than the four listed above. A previous study of this type was performed by Kaiser and Alexander

(reference 14). The larger amount of data has lowered the noise level which they encountered, but the results are the same. All of the major peaks can be identified as a harmonic or a combination of the low-order harmonics of the major periods. Other triggers of Jovian emission, for example, variations in the solar wind which should have a period of approximately 25 days if they recur with the rotational period of the sun, are not apparent in the data suggesting they are marginally periodic, aperiodic, or nonexistent.

The four major periods can be divided into observer-related and source-dependent groups. We have already discussed the earth's 24 hour interruption and the method of reducing its influence. The 399 day Jovian synodic period is also a result of earth-based observations since the data quality depends critically on the Jupiter-earth-sun angle and to some extent on the distance of Jupiter from the earth. It is impossible to eliminate this cycle from purely ground-based stations, but the period is long enough that it has little effect on the following study of the shorter periods.

The intrinsic influences on the sources, Jupiter's rotation and Io's orbital period, have long been studied in the form of plots of occurrence probability versus System III central meridian longitude and the phase of Io from superior geocentric conjunction. Figures 3 through 10 are plots of this type for the frequencies having more than 3000 hours of listening time in the catalog. Occurrence probability is computed for each 2 x 2 interval of longitude and Io phase and then represented by one of

64 shades of grey normalized so that the maximum probability is completely black. Clearly for some of the lesser-observed frequencies the variations are not smooth and the data are thinly spread. This is especially obvious from the oft-appearing shallow upward slant of the pattern, since a single storm appears as a line with a slope equal to the 10-hour Jovian rotational period divided by the 42-hour cycle of Io's orbital phase relative to the earth.

Figures 3 through 10 present a steady progression from dominance of Io-independent radiation to almost complete control of Jovian emission by the position of Io. Some of the features of the higher probability regions, commonly called "sources", are quite persistent through the frequencies with the exception of the transition from 10 MHz to 15 MHz (Figures 3 and 4). Although 10 MHz is one of the lesser-observed frequencies a year-by-year analysis shows features, such as the band of radiation centered at 200 longitude, which are long-lasting characteristics of this frequency though absent at higher frequencies. The apparent discontinuity at 10 MHz as well as other details of the dependence of source morphology on frequency have been discussed in Thieman and Smith (reference 12).

To what level of detail are the features observable in the sources repetitive and therefore indicative of a stable pattern of emission? This can be readily tested by dividing the 22 MHz data into two groups: observations made after conjunction but before opposition, and observations after opposition but before conjunction. Figures 11 and 12 are plots made from these groups.

Comparison of the plots shows that many of the finer details of the sources remain stable for periods of at least months since the plots have no observation times in common and the features must last long enough to appear on both plots and occur often enough to be distinguishable. (The after-opposition plot is not as smooth as its counterpart since observing sessions after opposition are centered on the early evening hours when the earth's ionosphere is still adjusting from the daytime solar influence making reception more difficult.) The obvious reproducibility even to the bulges in the high probability source regions implies that the beaming pattern is both complex and stable. Also, there is no evidence of change in observed source structure with the local time of the observer relative to Jupiter, but the difference in the average Jupiter-sun-earth angle between the two plots is quite small (approximately  $10^\circ$  to  $15^\circ$ ). Thus, the morphology of the features appears to be reproducible down to levels of occurrence probability of the order of 25% or less.

### Conclusion

Some will argue that the extensive data from the Voyager planetary radio astronomy experiments makes the synoptic monitoring results obsolete. Even as only a basis of comparison the ground-based observations are a valuable aid to the interpretation of Voyager findings. Though the spacecraft return round-the-clock data, there is still incomplete coverage of all

longitude-Io phase combinations, and nearly all observations are from positive Jovicentric declinations. Thus the earth-based catalog complements Voyager in the DAM frequency range. In addition, the temporal extent of the data base provides the means for measuring long period changes in the sources, of the order of years.

In summary, the combination of the output of many observing sites suppresses the effects of the earth's rotation on the data and radio storms missed by one station are often picked up by others. Analysis of periodicities within the data shows no statistically significant peaks for the solar rotation period or other unknown periodic influences. System III longitude versus Io phase occurrence probability diagrams are quite similar in the morphology of the high probability Io-related sources from one frequency to the next. Only in the transition from 15 MHz to 10 MHz do the plots appear to differ markedly. Within each frequency the source morphology remains remarkably consistent with time as evidenced by separate plots of 22 MHz data before and after opposition.

Finally, for those interested in obtaining the cataloged data, a copy of the master catalog tape will be deposited in the National Space Science Data Center within Goddard Space Flight Center. A copy of this tape could then be obtained by contacting either the center or this author.

#### Acknowledgments

This work was made possible by a research associateship from the National Academy of Sciences/National Research Council. Data have been provided through the cooperation of the radio astronomy observing groups at the Universities of Florida and Texas and the Goddard Space Flight Center. W. W. Richardson and A. G. Smith of the University of Florida and J. K. Alexander, M. L. Kaiser, S. S. Vaughan, and P. G. Harper of GSFC are especially to be thanked for their aid in the preparation of this catalog.



Table I  
STATION CODE LETTERS

<u>Code Letter</u>	<u>Station</u>
A	Tracking Station, Carnarvon, W. A., Australia
C	Clark Lake Radio Observatory, Borrego Springs, California
F	University of Florida Radio Observatory, Old Town, Florida
G	Goddard Space Flight Center, Greenbelt, Maryland
H	Maipu Radioastronomical Observatory (Field Site), Huanta, Chile
I	Kodaikanal Astrophysical Observatory, Kodaikanal, India
K	NASA/STDN Station, Kauai, Hawaii
M	Maipu Radioastronomical Observatory, Maipu, Chile
N	Nancay Radio Astronomy Observatory, Nancay, France
O	NASA/STDN Station, Orroral Valley (Canberra), Australia
S	NASA/STDN Station, Grand Canary Island, Spain
T	University of Texas Radio Astronomy Observatory, Marfa, Texas
Y	Bethany Observing Station, Yale Observatory, New Haven, Connecticut

Table II

## FREQUENCY STATISTICS

<u>Freq. (MHz)</u>	<u>Station Code</u>	<u>Years</u>	<u>Activity (Hours)</u>	<u>Listening (Hours)</u>	<u>Occur. Prob.</u>
5	M	1961-64	24.4	447.4	0.055
10	F	1965-67	133.2	1057.2	0.126
	M	1961-66	295.0	2264.7	0.130
	H	1965-66	3.2	120.1	0.027
	T	1968,70-71	2.5	79.7	0.031
			<u>433.9</u>	<u>3521.7</u>	<u>0.123</u>
12	F	1965-67	148.8	1245.9	0.120
13	M	1974-75	84.7	1513.1	0.056
15	F	1961-69,72-73,75-78	828.4	8928.7	0.093
	M	1961-62	276.0	2016.0	0.137
			<u>1104.4</u>	<u>10944.7</u>	<u>0.101</u>
16	M	1960,65-70,73-77	270.7	5656.4	0.048
	Y	1960,65-66	120.2	698.8	0.172
	T	1967-71	127.6	1303.9	0.098
	G	1965-78	1469.3	8919.4	0.165
	C	1966-67,69-74	219.4	3227.3	0.068
	K	1967-74,76-77	313.1	2037.8	0.154
	A	1966-72	106.3	1606.6	0.066
	S	1968-74	141.1	2788.9	0.051
	N	1977-78	170.8	718.1	0.238
	O	1977-78	34.2	334.9	0.102
			<u>2972.7</u>	<u>27292.1</u>	<u>0.109</u>
18	F	1957-78	1523.2	17657.9	0.086
	M	1960-77	827.1	14333.2	0.058
	H	1964-66	165.0	1508.9	0.109
			<u>2515.3</u>	<u>33500.0</u>	<u>0.075</u>
19	Y	1959-60	8.6	161.3	0.053
20	F	1964-78	745.9	14540.0	0.051
	M	1960-61	73.8	2001.6	0.037
	Y	1959-66	728.5	7230.4	0.101
	T	1967-71	122.2	1784.2	0.069
			<u>1670.4</u>	<u>25556.2</u>	<u>0.065</u>

Table II - continued

<u>Freq.</u> <u>(MHz)</u>	<u>Station</u> <u>Code</u>	<u>Years</u>	<u>Activity</u> <u>(Hours)</u>	<u>Listening</u> <u>(Hours)</u>	<u>Occur.</u> <u>Prob.</u>
22	F	1957-78	826.9	19761.2	0.042
	M	1960-61,63-77	443.9	14715.6	0.030
	Y	1958-66	631.0	9465.7	0.067
	T	1967-71	122.5	2643.0	0.046
	I	1962-67	136.9	2056.3	0.067
	G	1965-78	455.6	11882.2	0.038
	C	1969-74	82.1	5672.9	0.015
	K	1967-74,76-77	106.3	4320.4	0.025
	A	1966-72	49.4	3817.8	0.013
	S	1969-74	41.8	5022.6	0.008
	N	1977-78	43.1	894.3	0.048
	O	1977-78	19.8	1061.3	0.019
			<u>2959.3</u>	<u>81313.3</u>	<u>0.036</u>
23	Y	1958-60	17.5	485.5	0.036
25	F	1969-73	34.8	2183.8	0.016
27	F	1958-73,77-78	155.2	15793.1	0.010
	M	1960-77	<u>120.1</u>	<u>13763.5</u>	<u>0.009</u>
			<u>275.3</u>	<u>29556.6</u>	<u>0.009</u>
30	T	1967-71	31.5	3445.5	0.009
		Totals	<u>12281.6</u>	<u>221167.1</u>	<u>0.056</u>

Table III

## CATALOG RECORD DESCRIPTION

<u>Word No.</u>	<u>FORTTRAN Type</u>	<u>Description</u>
1	Integer	<u>Date</u> of event in year, month, day format as follows: YYMMDD. Observations continuing through 2400 hours UT are broken into separate days.
2	Integer	<u>Julian Date</u> of event less 2400000.
3	Integer	<u>Beginning Time</u> of event in hours and minutes in the form: HHMM (Universal Time).
4	Integer	<u>Ending Time</u> of event in hours and minutes in the form: HHMM (Universal Time).
5	Integer	<u>Frequency</u> in megahertz.
6	Alphabetic	<u>Station Code Letter</u> (see Table I).
7	Integer	<u>Listening or Activity Code</u> . Quality codes are often included for activity events (see Table IV).
8	Real	<u>Initial Central Meridian Longitude (1965)</u> in degrees.
9	Real	<u>Final Central Meridian Longitude (1965)</u> in degrees.
10	Real	<u>Initial Geocentric Phase of Io</u> in degrees.
11	Real	<u>Final Geocentric Phase of Io</u> in degrees.

Table IV

LISTENING AND ACTIVITY CODE DESCRIPTIONS

The seventh word in the catalog record is a three digit integer which has the following meaning in the ones, tens, and hundreds digits.

Listening Events

For all listening events all three digits of the code will be zero. Any number greater than zero represents activity.

Activity Events

Goddard Data - ones digit only

- 1 - All activity

Florida Data - ones digit only

- 1 - Certain Jupiter activity
- 2 - Probable Jupiter activity
- 3 - Possible Jupiter activity

Texas Data\*

Hundreds digit - storm type

- 1 - Main storm in observing time
- 2 - Precursor in observing time
- 3 - Post-cursor in observing time
- 4 - Main storm outside observing time
- 5 - Precursor outside observing time
- 6 - Post-cursor outside observing time

Tens digit - storm strength

- 0 - Not specified
- 1 - Strong (peak flux greater than 20 times Cygnus A)
- 2 - Moderate (peak flux 10-20 times Cygnus A)
- 3 - Weak (less than 10 times Cygnus A)

Ones digit - storm credibility

- 1 - Certain (probability event is Jovian 99%)
- 2 - Probable (probability event is Jovian 90%)
- 3 - Possible (probability event is Jovian 50%)
- 4 - As in 1, but may be solar emission
- 5 - As in 2, but may be solar emission
- 6 - As in 3, but may be solar emission

\* Observing time for Texas data is defined as the time when a radio storm exceeding a predetermined threshold flux could be detected if present. This table and other information on the Texas data code is condensed from reference 7.

Table V

## OCCURRENCE PROBABILITIES FOR SIMULTANEOUS OBSERVATIONS AT 22 MHz

<u>Common Obs. Time (hrs)</u>	<u>Station 1*</u>		<u>Station 2*</u>		<u>Common Act. Occ. Prob.</u>
	<u>Code</u>	<u>Occ. Prob.</u>	<u>Code</u>	<u>Occ. Prob.</u>	
5224.4	F	0.031	G	0.040	0.020
8282.7	F	0.043	M	0.033	0.021
1288.9	F	0.023	T	0.058	0.021
3839.0	F	0.056	Y	0.084	0.043
5671.0	G	0.039	M	0.025	0.015
1202.6	G	0.034	T	0.050	0.027
1368.1	M	0.013	T	0.047	0.010
2361.8	M	0.052	Y	0.082	0.037

\* The station code letter is interpreted in Table I.

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## Figure Captions

Figure 1. Mercator plot of the world showing the locations of the decameter-wave radio observatories contributing data to the catalog. The station code letters are interpreted in Table I.

Figure 2. Relative spectral power versus period for all Florida 22 MHz data (upper panel) and all 22 MHz data (lower panel) in the catalog. In the lower plot the major peaks are labeled according to the harmonics of the four major periods which form them (earth's rotational period, E; Jupiter's rotational period, J; Io's synodic period relative to Jupiter, Io; and Jupiter's synodic period relative to the earth, J<sub>s</sub>). The method of computation is described in Kaiser and Alexander (reference 12).

Figure 3. Normalized occurrence probability of 10 MHz radio emission versus central meridian longitude and the position of Io from superior geocentric conjunction (Io phase). Occurrence probability is represented by one of 64 shades of grey for each 2 x 2 interval in longitude and Io phase. The probabilities are normalized so that the highest value is black.

Figure 4. Same as for Figure 3, but for 15 MHz data.

Figure 5. Same as for Figure 3, but for 16 MHz data.

Figure 6. Same as for Figure 3, but for 18 MHz data.

Figure 7. Same as for Figure 3, but for 20 MHz data.

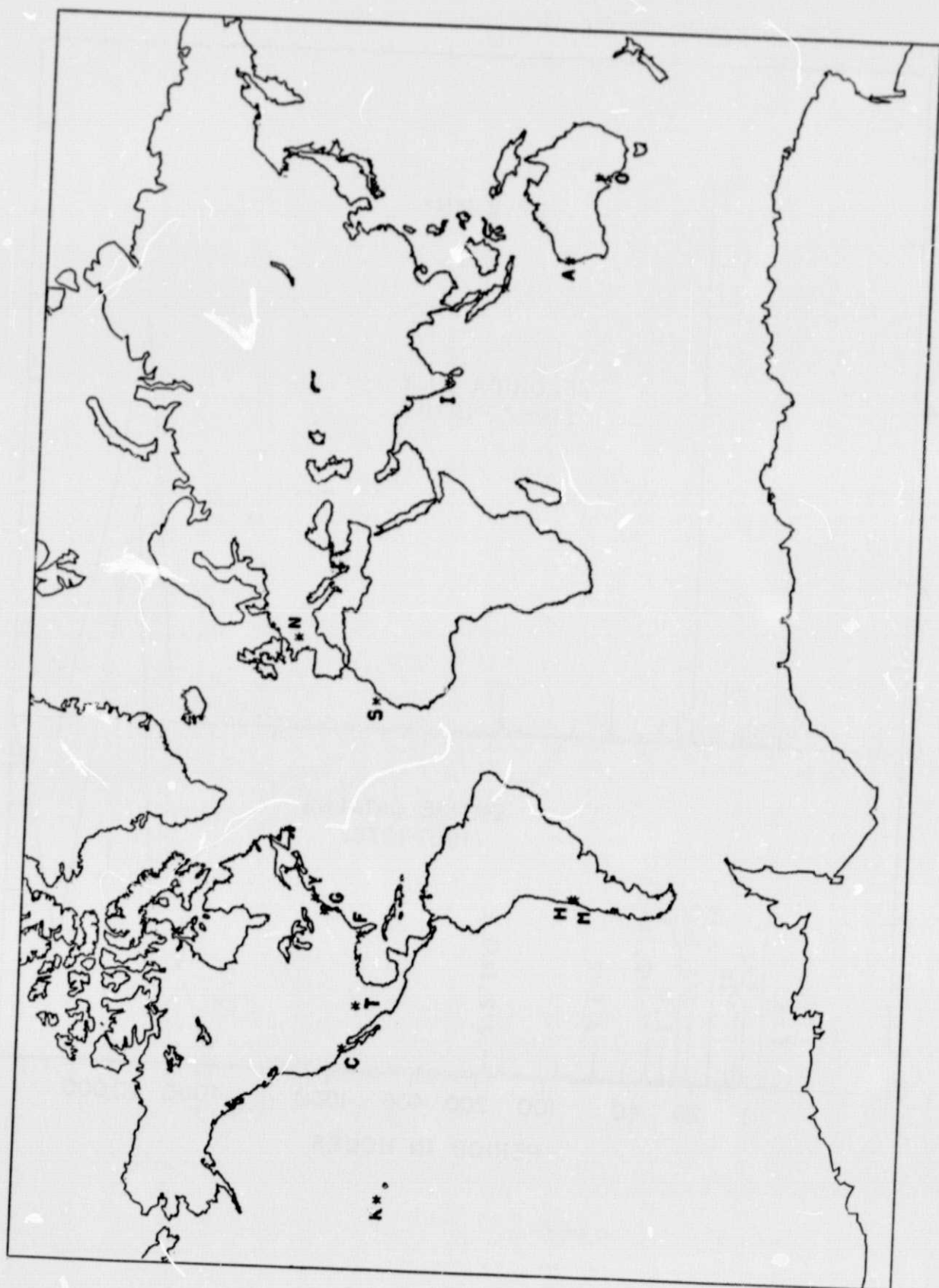
Figure 8. Same as for Figure 3, but for 22 MHz data.

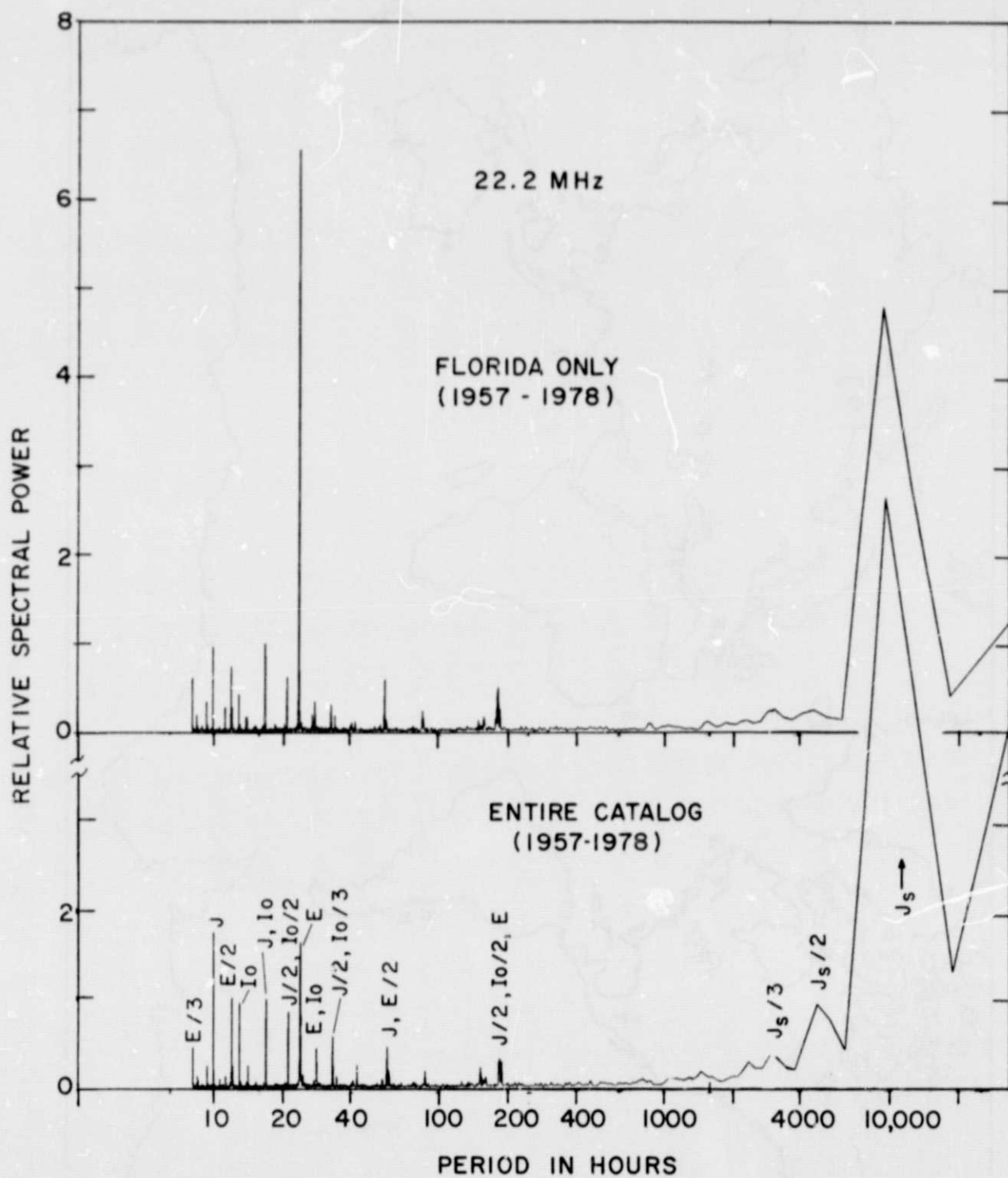
Figure 9. Same as for Figure 3, but for 27 MHz data.

Figure 10. Same as for Figure 3, but for 30 MHz data.

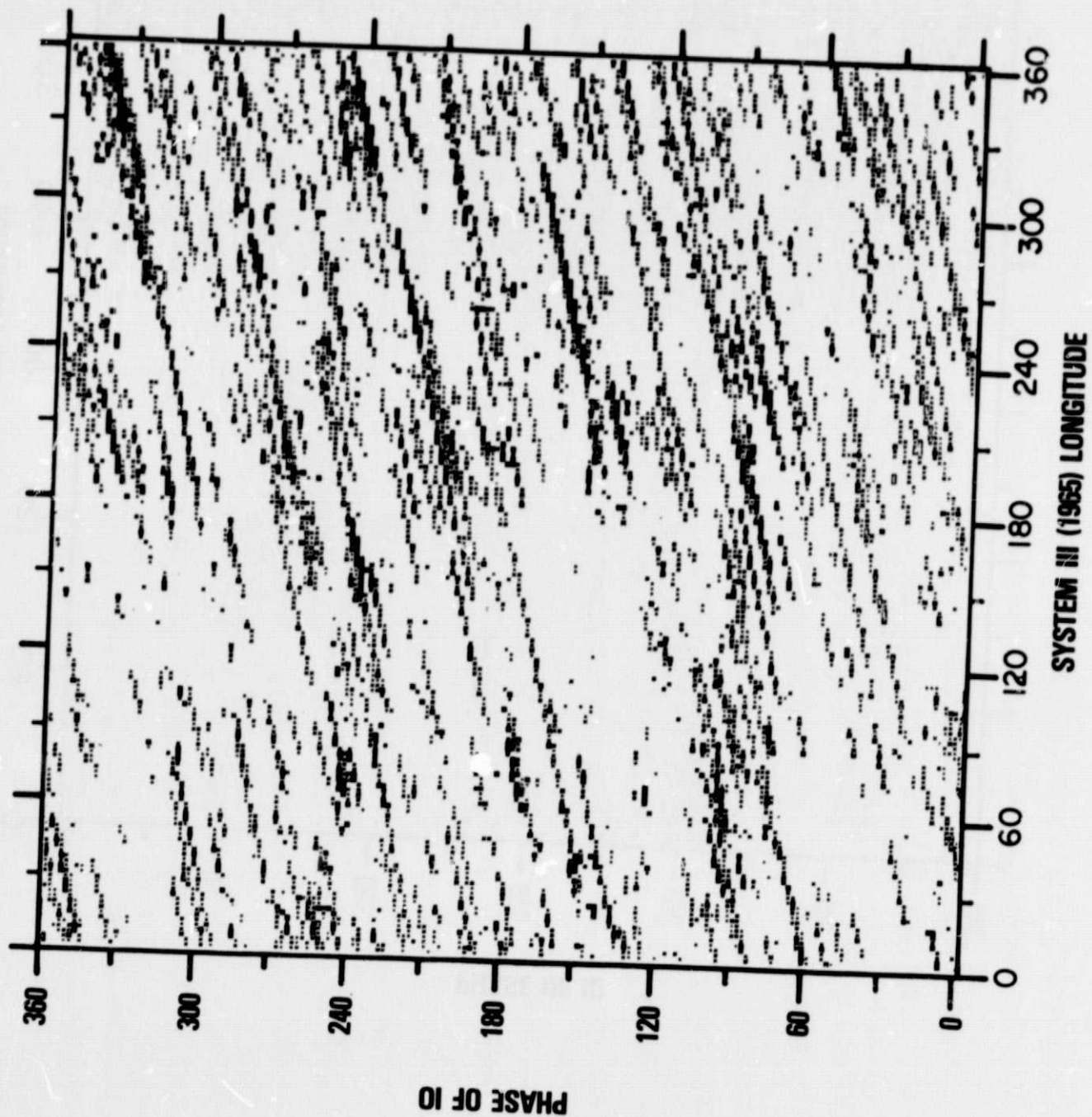
Figure 11. Same as for Figure 3, but for all 22 MHz data after conjunction and before opposition.

Figure 12. Same as for Figure 3, but for all 22 MHz data before conjunction and after opposition.



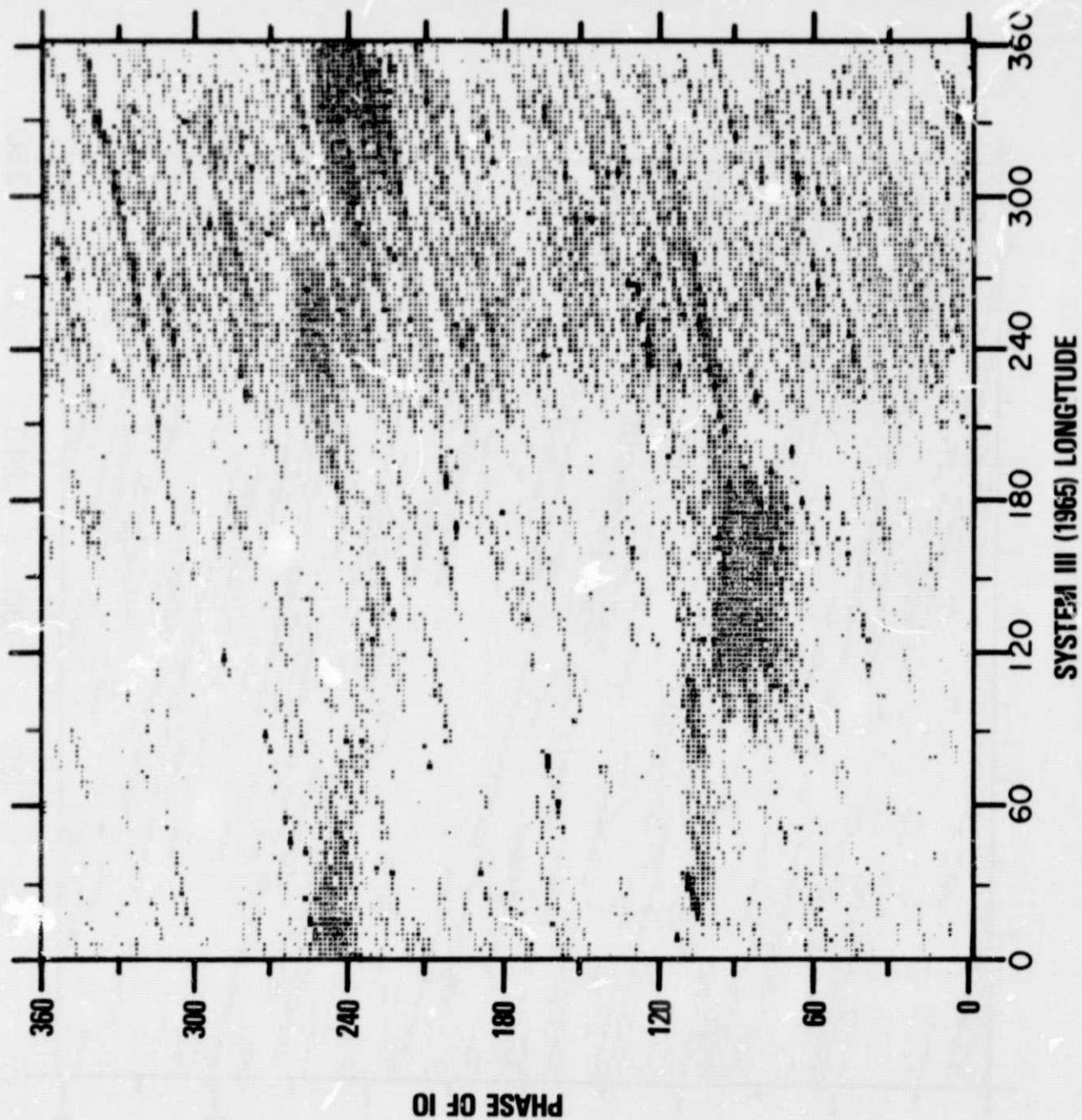


10 MHz



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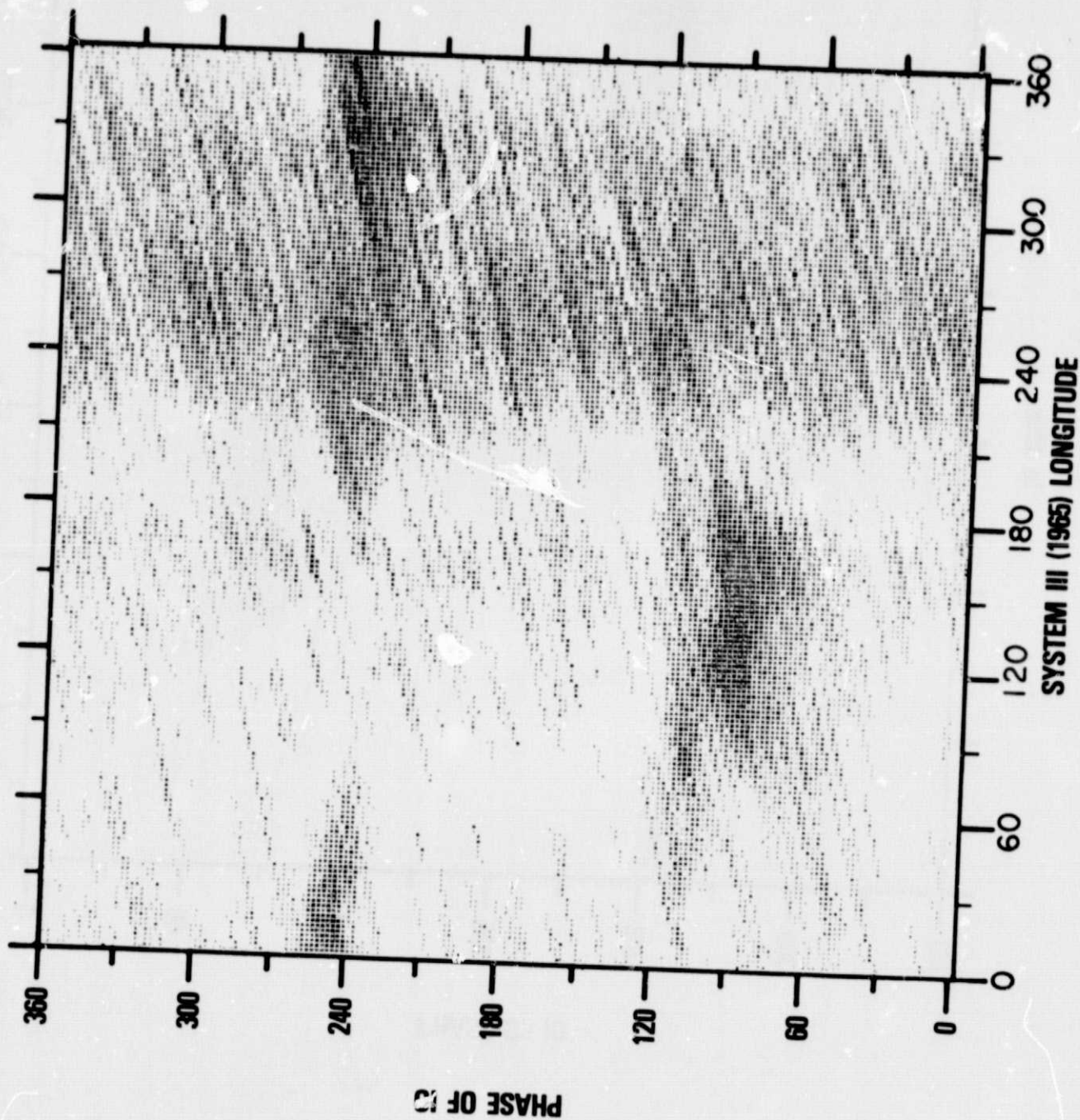
15 MHz



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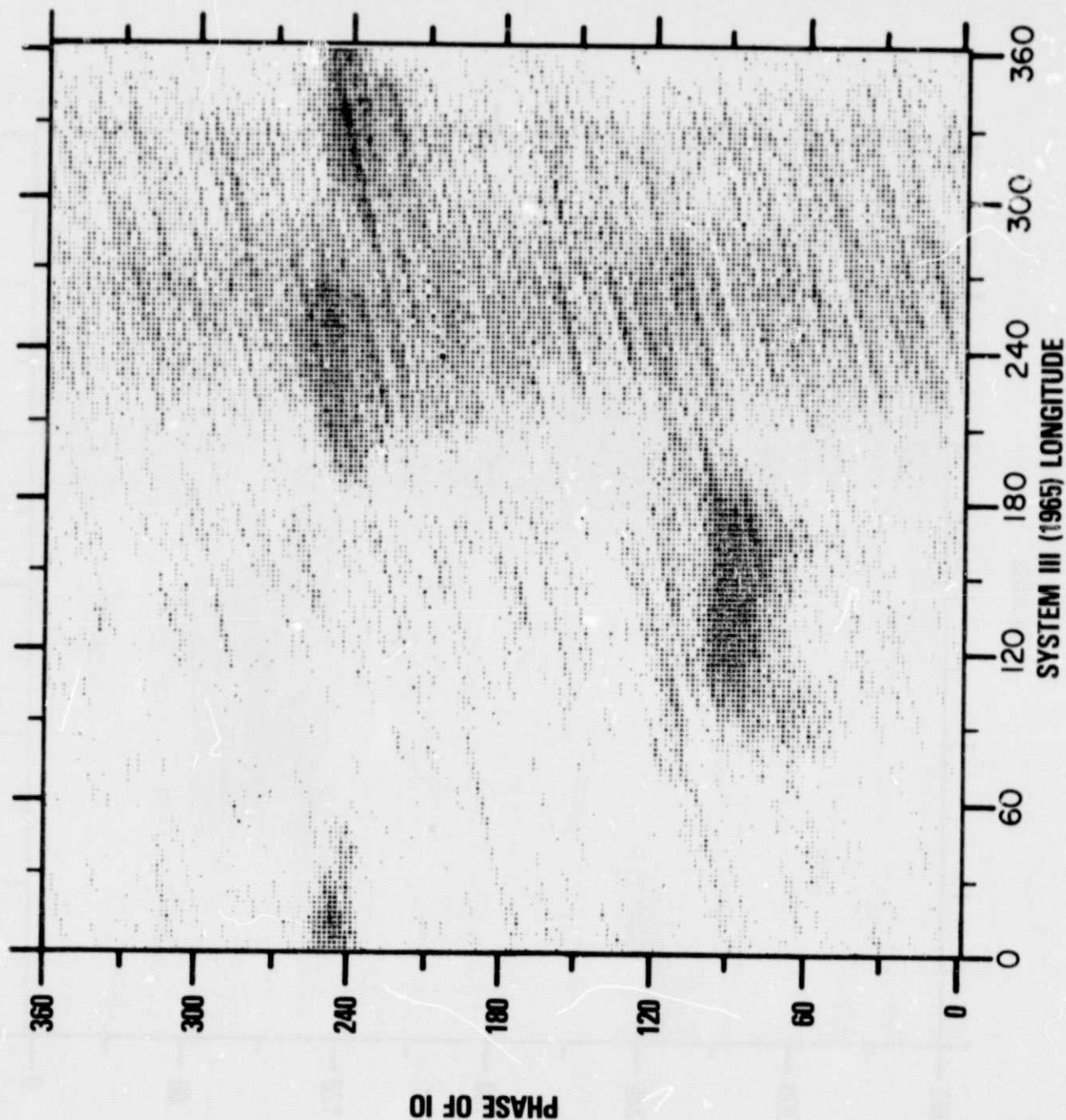


16 MHz

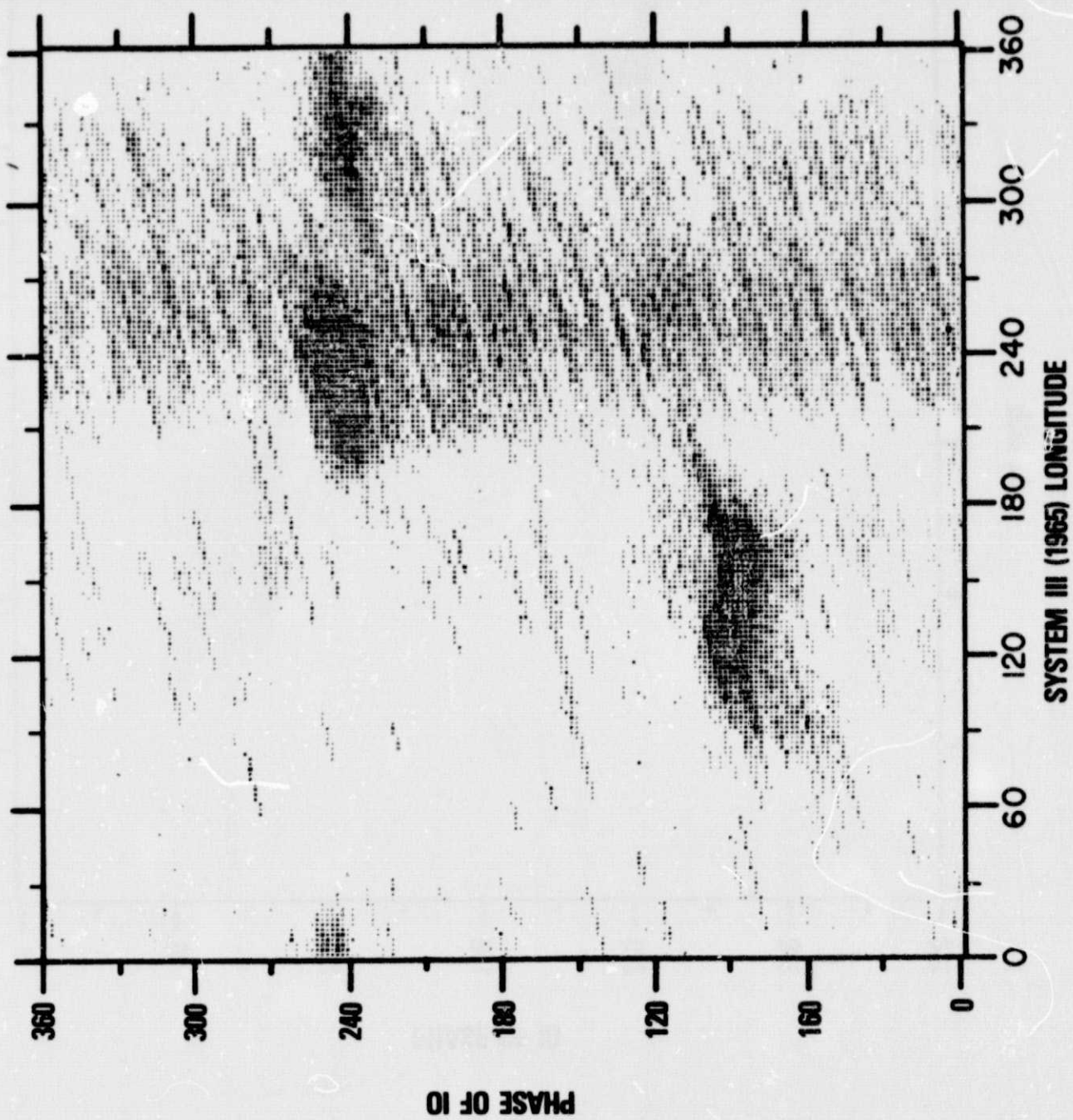


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18 MHz

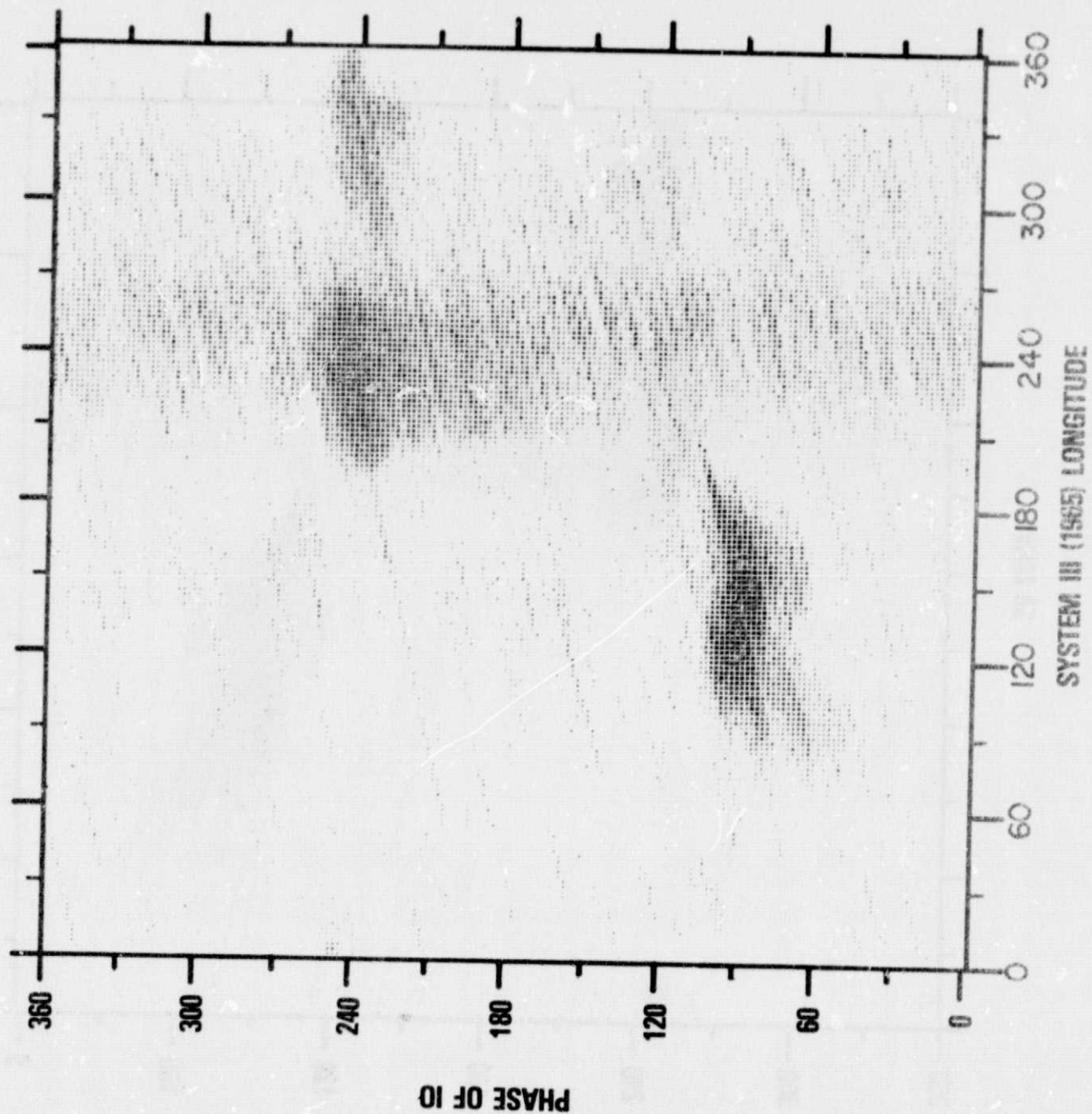


20 MHz



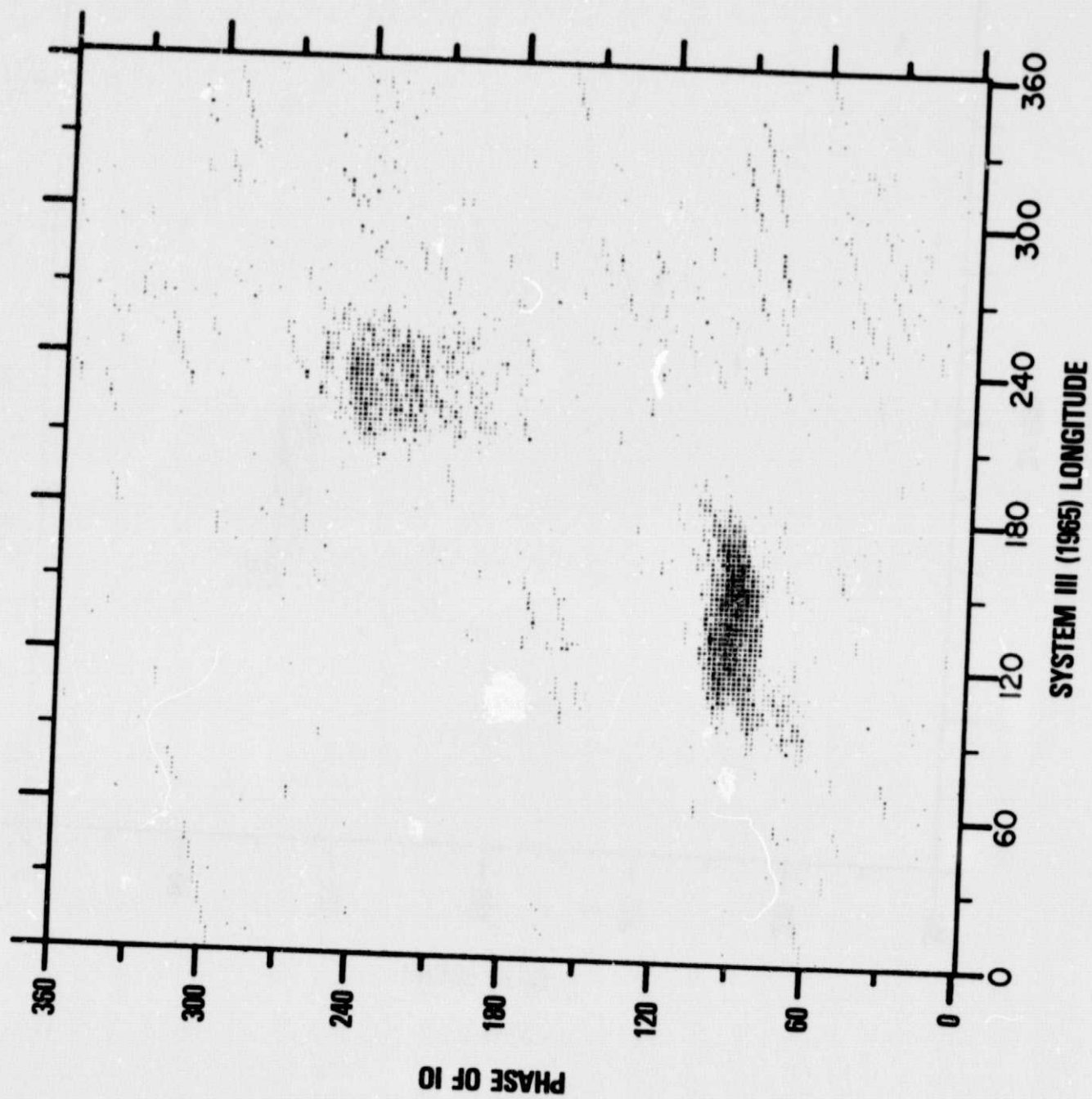


22 MHz

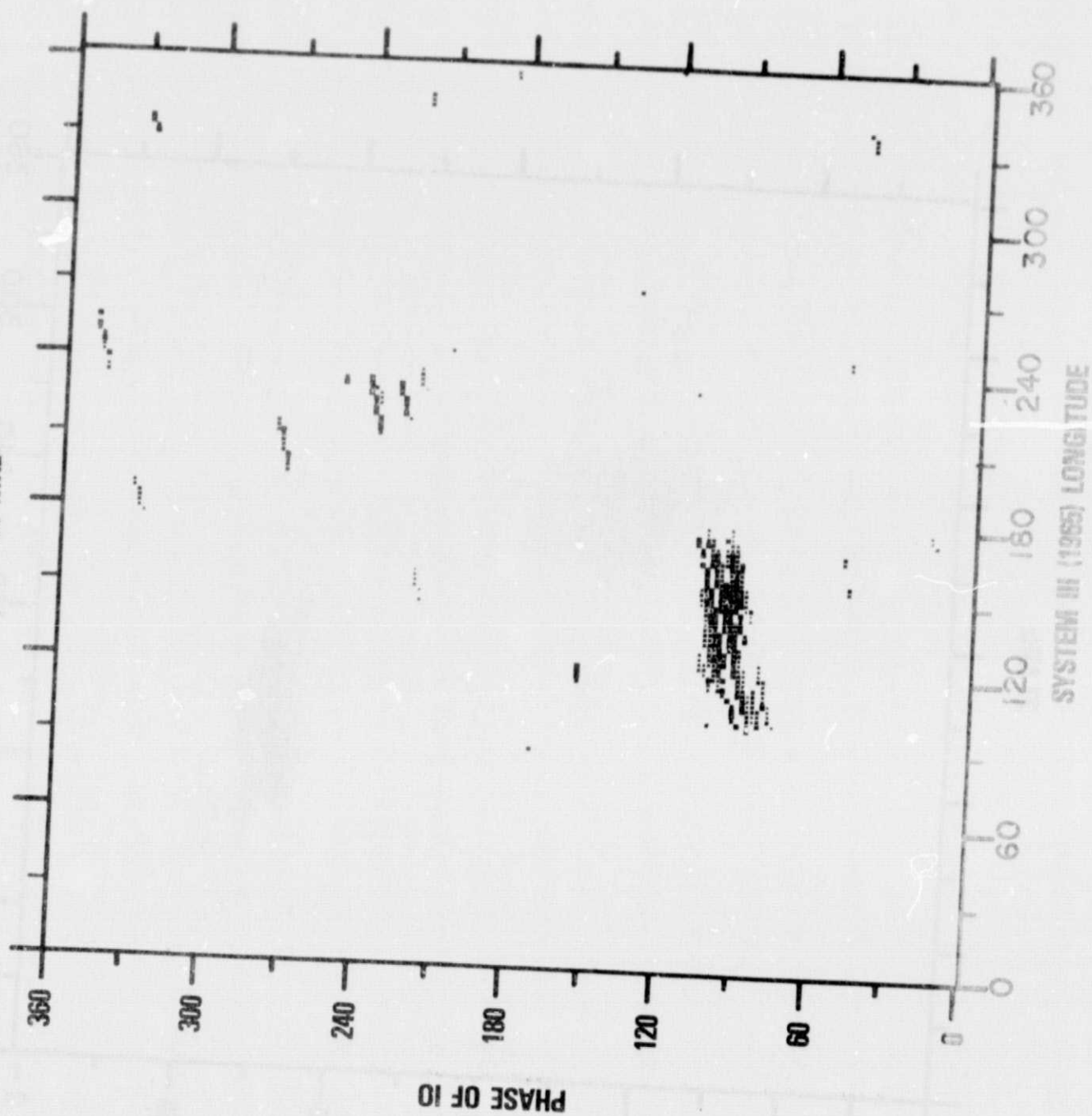


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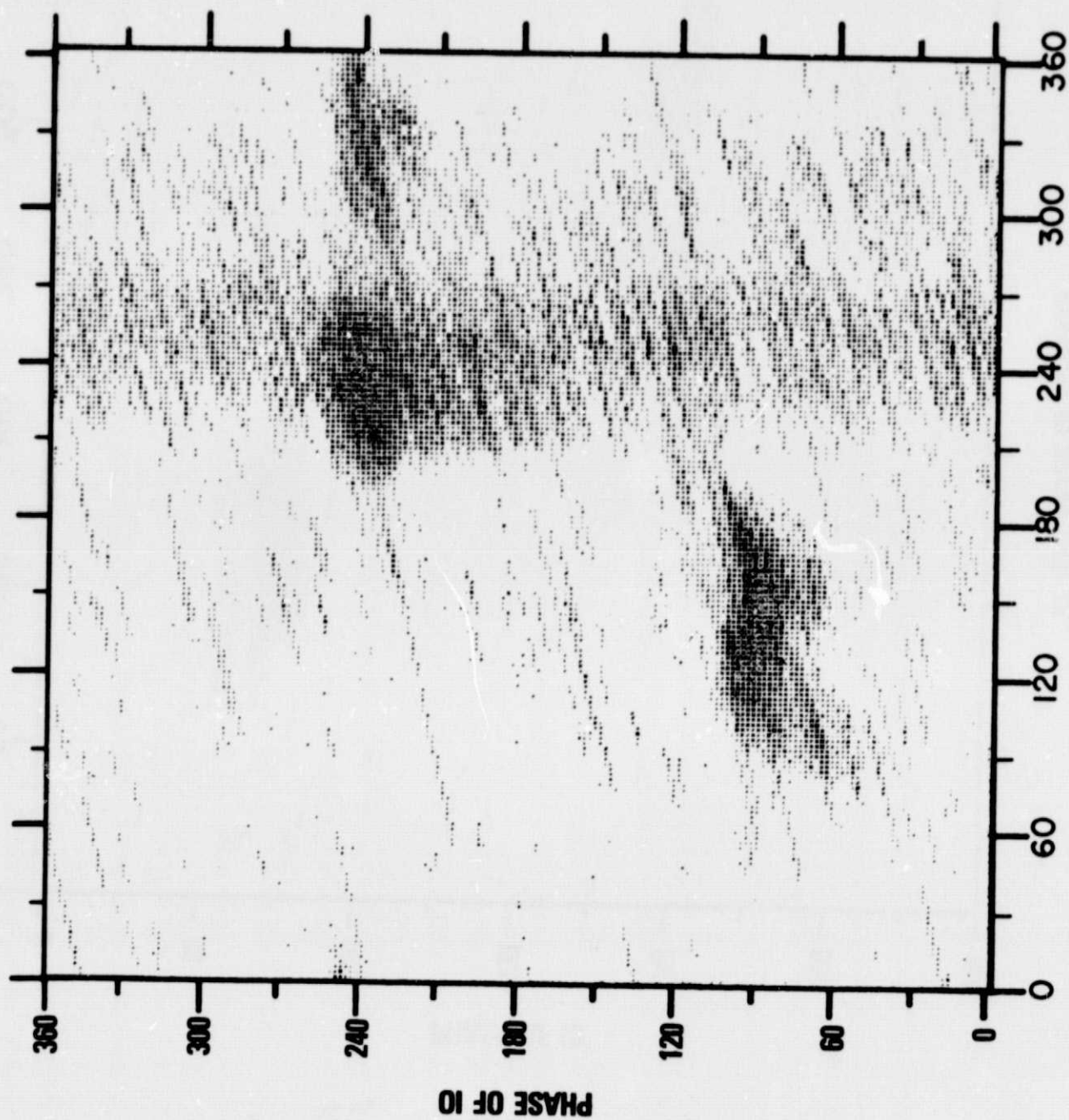
27 MHz



30 MHz



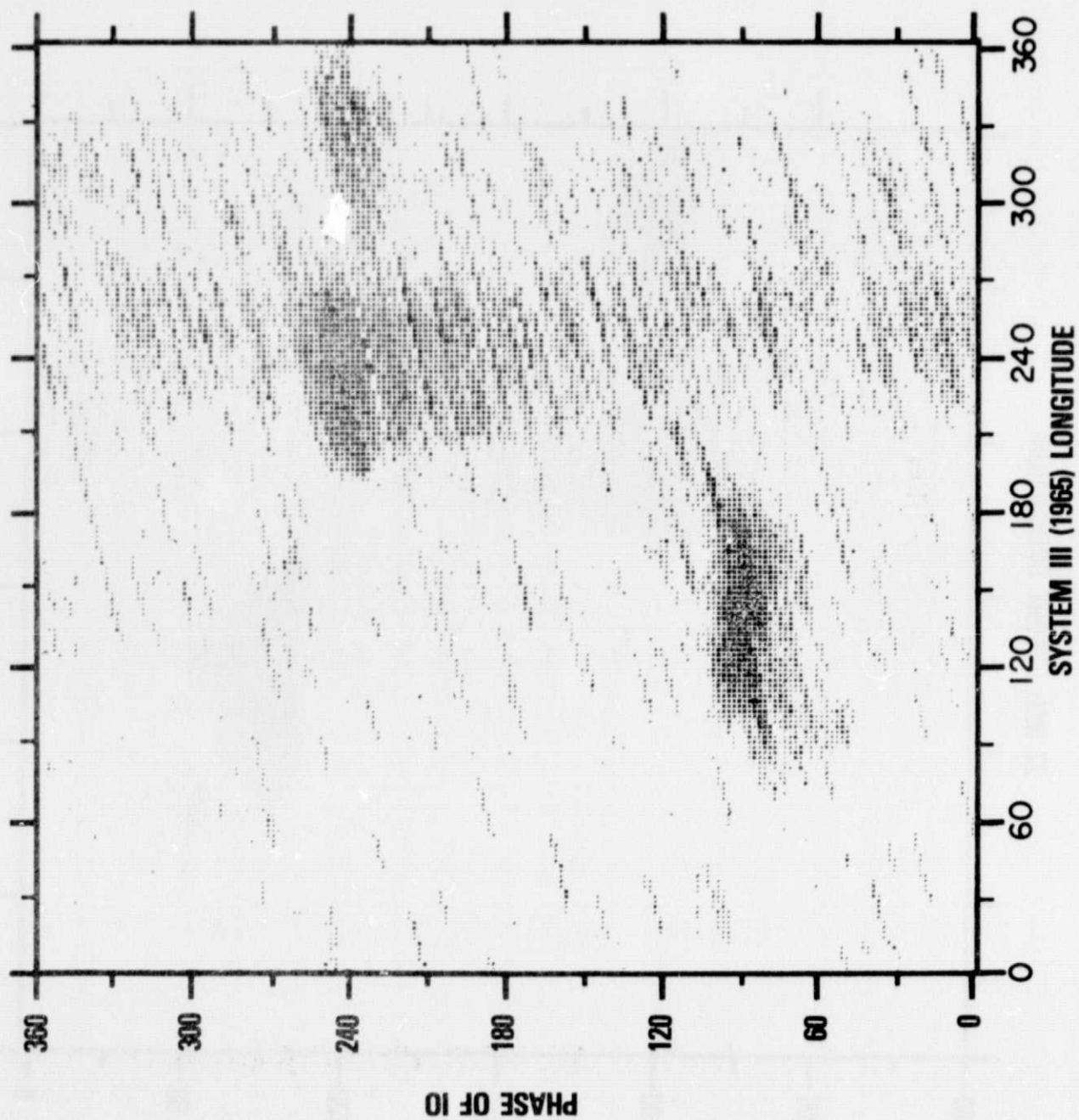
22 MHz BEFORE OPPOSITION



SYSTEM III (1965) LONGITUDE



22 MHz AFTER OPPOSITION



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